Design of a Constructed Wetland for Treatment of Facultative

Lagoon Effluent in Rural Alaska

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A

PROJECT

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Abstract

Many rural communities in Alaska rely on large constructed lagoons to treat their wastewater. The quality of effluent released from these lagoons and the ability of the receiving bodies to dilute the effluent varies as the thawed season progresses. The receiving bodies tend to have capacity before the effluent has reached levels acceptable for discharge and algae growth degrades effluent quality as capacity in receiving bodies is decreasing, leaving only a short window to discharge effluent with minimal impact.

The expansion of an existing facultative lagoon and the addition of a constructed wetland in Galena, Alaska is estimated to increase BOD and TSS removal to levels that will consistently exceed permit levels. The lagoon will be drawn down by discharging to the constructed wetland over a 120 day discharge period. The addition of the constructed wetland will keep TSS within permit levels even when algae drives TSS values over permit levels in the facultative lagoon. While the constructed wetland is expected to reduce fecal coliform concentration in the wastewater treatment facility effluent it may not bring fecal coliform levels down to below permit levels. Additional dilution or disinfection may be required.

Unlike BOD, TSS, and fecal coliform, which are expected to improve through the addition of the constructed wetland, dissolved oxygen levels are expected to decrease as a result of treating the wastewater in the constructed wetland. While the dissolved oxygen concentration of the constructed wetland effluent will be low, the decreased BOD concentration will result in an effluent that is more readily able to reaerate over an effluent with a higher BOD concentration. Overall the results of this project suggest that adding constructed wetlands treatment to facultative lagoons prior to discharge to receiving bodies has the potential to create effluent of consistent quality that will meet or exceed ADEC permit requirements.

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Acres…………………………………………………………………………………………ac

Alaska Department of Environmental Conservation………………………………………ADEC

Alaska Department of Economic and Community Development……………………….ADECD

Average Daily Flow…………………………………………………………………………ADF

Biochemical Oxygen Demand…………………………………………………………..BOD

Carbonaceous Oxygen Demand………………………………………………………..COD

Colony Forming Unit…………………………………………………………………………cfu

Dissolved Oxygen…………………………………………………………………………DO

Enforcement and Compliance History Online……………………………………………..ECHO

Fecal Coliform………………………………………………………………………………FC

Free Water Surface…………………………………………………………………………..FWS

Gallons per Day………………………………………………………………………………gpd

Gallons per Capita per Day…………………………………………………………………..gpcd

Hectare……………………………………………………………………………………….ha

Hydraulic Residence Time…………………………………………………………………HRT

Pounds…………………………………………………………………………………………..lb

Kilogram……………………………………………………………………………………….kg

Liter…………………………………………………………………………………………….L

Meter………………………………………………………………………………………….m

Milligram……………………………………………………………………………………….mg

Milliliter………………………………………………………………………………………….mL

Operations and Maintenance………………………………………………………………O&M

Square Feet……………………………………………………………………………………sf

Substrate Flow System……………………………………………………………………SFS

Total Suspended Solids……………………………………………………………………TSS

United States Environmental Protection Agency…………………………………………..EPA

Chapter 1 Background

1.1 Introduction

Rural communities across Alaska face a need for safe disposal of wastewater. Small rural communities do not generally have the resources to build or operate conventional wastewater treatment works, so they rely on effects such as sedimentation, bacterial oxidation, and dilution to provide a minimal level of treatment. Constructed lagoons, tundra ponds, and untreated sewage discharged directly to tidal water are three predominate ways wastewater is disposed of in rural Alaska (Schubert, 2009).

Although untreated sewage discharge into surface waters is less common than treatment through tundra ponds or constructed lagoons, many tundra ponds and constructed lagoons ultimately discharge into wetlands or surface waters without achieving minimal Environmental Protection Agency (EPA) standards (Schubert, 2009). The quality of effluent from constructed lagoons, in particular, can be increased by adding constructed or natural wetlands treatment prior to discharge.

1.2 Facultative Lagoon Treatment in Alaska

Facultative lagoons are the most common form of wastewater treatment in rural Alaska (Schubert, 2009). In Alaska, the Department of Environmental Conservation (ADEC) required minimum retention time for a constructed lagoon is 240 days and retention times as long as one year are common. This results in lagoons that are generally very large (Smith, 1996). The long retention time is due to long periods of ice cover that greatly slow the treatment process and effect receiving bodies.

During the thawed season, when the lagoon is exposed to oxygen, treatment is achieved by aerobic, facultative, and anaerobic processes. During the period of the year when the lagoon is covered in ice, slower anaerobic processes continue to provide treatment. The anaerobic treatment achieved while the lagoon is covered in ice is typically not adequate to allow discharge from the lagoon. Lagoons are primarily used for wastewater storage during the winter months and effluent is released after the ice has melted and aerobic treatment can occur.

Many facultative lagoons in rural Alaska discharge to rivers (Smith et al., 1996). Rivers are typically fed from a range of water sources including shallow groundwater, rainfall runoff, and melting snow. In Alaska melting snow causes seasonally high flows in the spring resulting in peak dilution capacity in late spring and early summer. Over the course of summer the river flows tend to decrease, resulting in less dilution capacity (Smith et al.,1996). Seasonal flow from the Yukon River is shown in Figure 1.1.

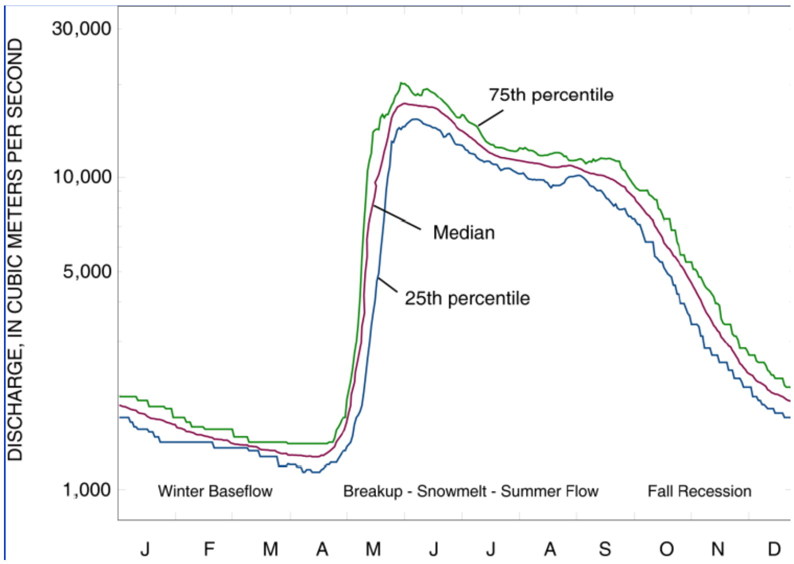

Figure 1.1: Yukon River discharge at Pilot Station.

(Source: Brabets and Walvoord, 2009).

While receiving body dilution capacity is at its peak during spring due to snowmelt runoff, constructed lagoons require one to two months of ice-free operation to reach acceptable Biochemical Oxygen Demand (BOD) levels. As levels of BOD from wastewater improve due to aerobic conditions algae can cause an increase in BOD and Total Suspended Solids (TSS) at the peak of its growth around mid to late summer, as shown in Figure 1.2 (Smith et al., 1996). The increase in algae is a result of increased sun exposure in summer months and must be considered when discharging lagoon effluent. The growth of algae can contribute to the treatment of wastewater by transforming solved nutrients into particle aggregates, but can also degrade receiving bodies if allowed to escape with effluent (Steinmann et al, 2003). If not adequately diluted in the receiving body, algae can exert an oxygen demand and cause decreases in oxygen levels and increases in suspended solids levels that can degrade water quality (Gschlöbl et al, 1998). This situation can be disastrous if the degradation of water quality affects wildlife in areas where people rely on the receiving body for subsistence fishing or hunting.

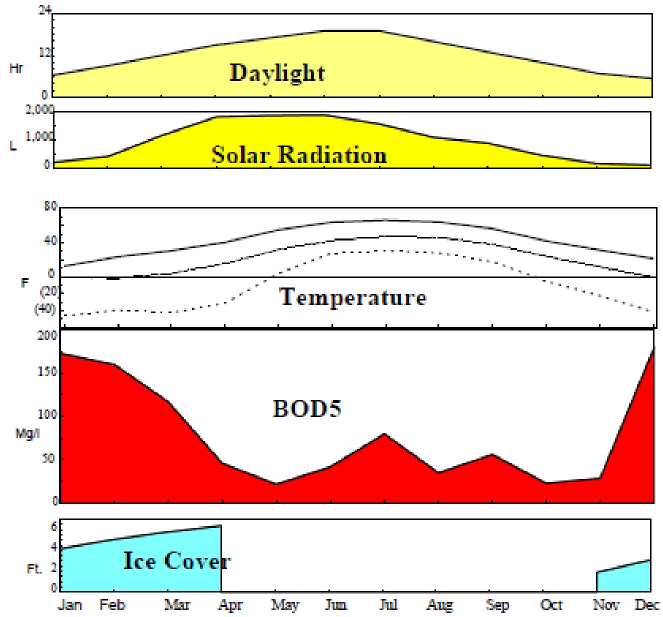

Figure 1.2: Seasonal lagoon performance factors Bethel, Alaska.
(Source: Schubert, 2009)

The seasonal peak in flow that occurs in the spring represents the optimal time to achieve maximum dilution for the effluent. However, the peak flow roughly corresponds with the period of time when lagoon effluent is high in BOD due to the months of ice cover and anaerobic treatment. Further complicating the timing of effluent discharge is the increase in algae that occurs in mid to late summer when BOD levels drop and drives up TSS. One way to manage the timing of effluent discharge is to provide additional treatment in the form of constructed wetlands to remove the additional BOD in spring and the additional TSS in mid to late summer.

1.3 Wetlands Treatment Overview

Wetlands act as a transition area between dry land, or uplands, and aquatic areas, such as rivers or lakes. Natural wetlands act as natural filters, cleaning runoff before it enters more pristine waters. The soil is saturated for at least part of the year and the plants are adapted to an absence of oxygen caused by microbial action (Helfferich, 2004). The filtering characteristics of natural wetlands can be harnessed as a means to treat wastewater. Natural wetlands can also be imitated, in the form of constructed wetlands, and used as part of a wastewater treatment system. Wetlands can be used to treat primary or secondary effluent to tertiary levels (Doku and Heinke, 1994). Wetlands treatment systems have advantages over conventional treatment systems that make them attractive for small isolated communities. Wetland systems can be established in the same location the wastewater is produced, they can be maintained by relatively untrained personnel, and they require relatively low energy and low costs to operate. (Solano et al, 2003). In Alaska, a massive state with a land mass of 403,247,700 acres, natural wetlands make up over 43.3% of the total state and wetland plants may be available to harvest locally for use in a constructed wetland (Hall et al, 1994).

Some challenges are present in natural wetlands treatment that are not in constructed wetland treatment. Natural wetland areas generally feed water directly into aquatic areas including rivers, lakes, and groundwater. In order for a natural wetland to be used for treatment, the wastewater must be contained within the wetland long enough to achieve treatment prior to entering aquatic areas. Concerns about the natural ecology and biodiversity of a natural wetland may also prevent it from being used to treat wastewater (Asano et al, 2007). The EPA specifically discourages the use of natural wetlands in wastewater treatment in their design guidance, which could result in difficulty getting a permit to use a natural wetland for wastewater treatment (EPA, 1999). Additionally the US Army Corps of Engineers regulates wetlands as Waters of the US and may object to the use of natural wetlands for wastewater treatment (EPA, 1999). A constructed wetlands area may be an attractive alternative and can act as a means to create new habitat where effects to natural habitat are a concern.

There are two established types of constructed wetlands, free water surface systems (FWS) and subsurface flow systems (SFS). In FWS systems, Figure 1.3 (A), the wastewater does not infiltrate significantly into the soil. The plants provide a substrate for microbial growth that is thought to be responsible for treatment. In SFS systems, Figure 2 (B), the wastewater flows through the root zone where treatment occurs through a variety of microbial, chemical, and physical processes (Jenssen et al, 1993).

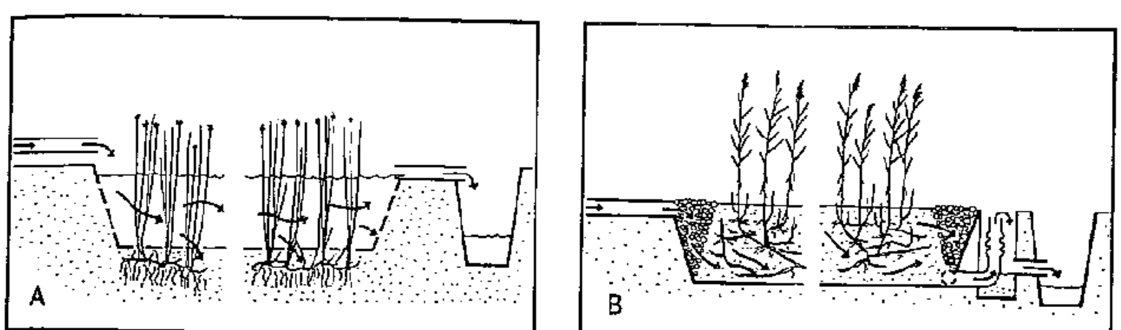

Figure 1.3: Constructed wetland profile view (A) FWS (B) SFS.
(Source: Jenssen et al, 1993)

Several studies have looked at the use of wetland treatment in cold climates or cold seasons. Most of these studies recommend SFS wetlands over FWS wetlands for use in cold climates or cold seasons. The SFS systems are thought to be better suited to cold climates due to the insulating effects plant litter and soil provide for bacterial communities (Werker et al, 2002). There is also a possibility of operating SFS systems at higher water levels prior to freezing to generate an insulating ice layer below which space can be available for air and water. Snowcover will add additional insulation to the SFS system, especially if snowcover occurs prior to formation of a significant ice layer (Wittgren and Mæhlum, 1997).

The recommendations of these studies do not appear to be suited to the extreme cold weather environments of rural Alaska where ice thickness can range from 40 to 70-inches and the underlying soils may be permanently frozen below a shallow active layer (Smith et al., 1996). In particular, these recommendations do not appear suited for lagoon effluent that will be near freezing temperatures when it enters the SFS wetland. Even with snow cover and an ice layer it is likely that a SFS constructed wetland exposed to the extreme freezing conditions that occur in much of Alaska will freeze solid for the full depth of the SFS. A SFS frozen to the full depth will take a considerable amount of time to return to service in the thawed season.

With the long hydraulic retention time (HRT) available to most rural Alaskan communities in the form of facultative lagoons it is not necessary to operate the constructed wetland year round, removing the need to operate the wetland during the freezing months.

1.4 Talkeetna Constructed Wetland

Talkeetna is a small unincorporated community of approximately 560 people located approximately 115 miles north of Anchorage at the end of the Talkeetna Spur Road. Talkeetna is located at the confluence of the Talkeetna and Susitna Rivers in Southcentral Alaska in an area of freshwater emergent and freshwater forested/shrub wetlands. Climate conditions in Talkeetna are summarized in Table 1.1.

Table 1.1: Climate conditions in Talkeetna, Alaska.

	Month												
Parameter	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Maximum Temperature(F)	22.2	27.6	35.6	46.1	58.5	67.0	68.5	65.2	55.8	40.6	26.8	23.7	44.9
Mean Temperature (F)	14.2	18.1	24.9	35.9	47.8	57.0	60.1	56.7	47.5	33.2	19.5	16.0	36.0
Minimum Temperature (F)	6.2	8.7	14.2	25.6	37.0	47.1	51.8	48.2	39.2	25.8	12.1	8.3	27.1
Precipitation (inches)	1.36	1.45	1.05	1.29	1.62	1.92	3.39	5.11	4.32	2.90	1.63	1.93	27.97
Snowfall (inches)	22.3	22.1	15.0	7.7	1.0	0.0	0.0	0.0	0.7	13.3	23.3	31.7	137.1

(Source: Alaska Climate Research Center (ACRC), 2015).

In October 2001 the Matanuska-Susitna Borough was given a Notice of Violation by the ADEC for surpassing water quality discharge standards from its sewage treatment facility in Talkeetna, Alaska. At the time the Notice of Violation was issued the treatment facility in Talkeetna consisted of two holding cells and a percolation cell (Maddux, 2005).

Approximately 40,000 gallons of sewage were pumped by force main to the Talkeetna lagoon facility per day. The effluent in the holding cells was typically transferred to the percolation cell twice per year – just after spring breakup and before the onset of winter. The Notice of Violation related to sludge build-up in the lagoons, percolation cell performance, and groundwater quality issues. A free water surface flow constructed wetland with a discharge to the Talkeetna River Slough was proposed as an alternative to discharging the effluent to the percolation cell (Maddux, 2005).

The constructed wetland was designed for a maximum treatment season of 145 days with a flow of 105,000 gpd, a surface area of 35,000 square feet, a theoretical hydraulic detention time of 1.86 days, and an HRT of 24.9 days. The constructed wetland consists of a continuous system of six cells with an operating depth of 12-inches and 4 feet deep water trenches between each cell. The six cells are planted with a total of five species of wetland plants. Cell 1 is planted with Typha latifolia (broad leaf cattail), cell 2 is planted with Scirpus validus (soft-stemmed bulrush), cell 3 is planted with Carex utricularia (common sedge), cell 4 is planted with Calla palustris (calla lily), cell 5 is planted with Carex aquatilis (blue-green sedge), and cell 6 is planted with Carex utricularia (common sedge). The plants were chosen based on four criteria; they are indigenous to the area, have an ability to colonize rapidly, are able to withstand high pollutant loads of ammonia and provide a large surface area for periphyton attachment. The calla lily was harvested from a lake in Fairbanks and transported to the site the same day it was harvested by truck. The other four plant types were purchased from a wetland nursery in Montana (Maddux, 2005).

The constructed wetland was put into use in mid-August 2003. The constructed wetland was shut down for the winter following an initial six week discharge period where the wetland produced exceptional initial reduction of pollutants. Water quality results the following year, 2004, were mixed. The TSS and BOD samples during the 2004 treatment season were well within the ADEC discharge parameters of 70 mg/L and 65 mg/L respectively. The fecal coliform, however, met the discharge standard of 20 cfu/100 ml only once out of four sampling events (Maddux, 2005). A diagram of the Talkeetna facility is provided in Figure 1.4. The design of the Talkeetna constructed wetland is one influence on the design of this project.

Figure 1.4: Talkeetna Constructed Wetland.

(Source: Adapted from Google Earth, 62° 20’ 02.90” N 150° 05’ 32.25” W, Image Date September 1, 2010, Retrieved March 23, 2015)

Chapter 2 Project Introduction

2.1 Project Purpose

The purpose of this project is to design a constructed wetland for the treatment of facultative lagoon effluent in a rural Alaska community. Facultative lagoon wastewater treatment is popular in rural Alaska where low cost and simple operation and maintenance are of foremost concern (Smith, 1996). The ADEC Lagoon Construction Guidelines (2009) require a total system HRT of 240 to 365 days for facultative lagoons. The long retention times of these facilities help make constructed wetland treatment practical in cold region communities of rural Alaska. The effectives of constructed wetland treatment is at least partially dependent on seasonal conditions (Stein and Hook, 2005). Studies have found that some plant species provide reduced treatment effectiveness during cold periods when they are not actively growing. The long retention times available in Alaskan facultative lagoons make it possible to wait until the growing season to discharge effluent for best results.

2.2 Selecting Project Location

The criteria used in the search for an appropriate community to serve as the focus of this project included a community with a facultative lagoon with a HRT of 240 days or more, discharge to fresh water, a location near an abundance of natural wetlands, and the availability of wastewater monitoring data. The search included consulting the ADEC for recommendations of communities that might meet the criteria, particularly for the reporting of monitoring data to the ADEC. Few communities were recommended and from the list Galen was found to be the most consist in reporting monitoring data. While Galena consistently reports monitoring data to the ADEC they are rarely fully compliant with their ADEC permit requirements. Over the eleven reporting quarters that are available on the Enforcement and Compliance History Online (ECHO) database Galena's compliance status has been listed as either Significant Non-compliance or Violation over all eleven quarters (EPA, 2015).

2.3 Physical Setting

Galena, Alaska is a community of approximately 470 people located along the Yukon River in Interior Alaska. Galena is located on the north bank of the Yukon River, 45 miles east of Nulato and 270 air miles west of Fairbanks (Alaska Department of Economic and Community Development (ADECD), 2015). Galena was established in 1918 and became a supply and trans-shipment point for nearby lead ore mines. A school was established in the mind-1920's and a post office opened in 1932. A military air field was constructed in World War II. Due to severe flooding in 1971 a new community site was developed about 1.5 miles east of the original town site where city offices, a health clinic, schools, a washeteria, a store, and more than 150 homes were constructed. Population in Galena peaked around 1990 with 833 reported residents. The Air Force station was closed in 1993 and the facilities are currently being used by the Galena School District as a boarding school with a current enrollment of 117 students. Future growth of the boarding school is desired up to 300 students. The population of Galena is mixed Athabascan and non-Native. Subsistence food sources include salmon, whitefish, moose, and berries (ADECA, 2015).

Galena is located in an area of freshwater emergent and freshwater forested/shrub wetlands as shown in Figure 2.2. Climate conditions in Galena are summarized in Table 2.1.

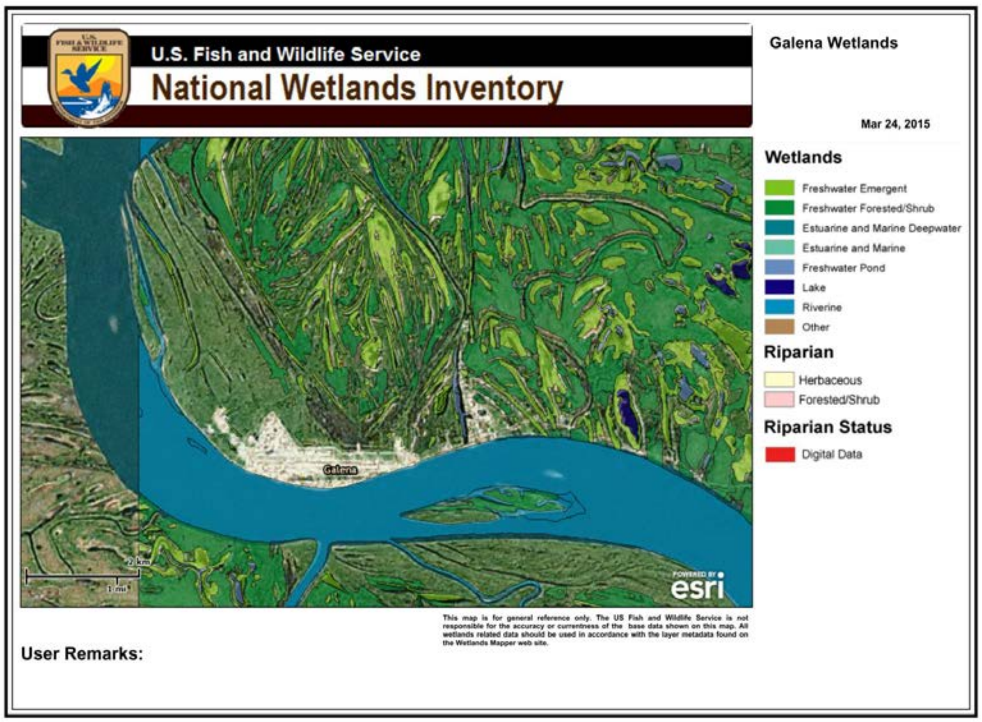

Figure 2.2: Galena area wetland map.

(Source: Unites States Fish and Wildlife Service (USFWS), 2015)

Table 2.1: Climate conditions in Galena, Alaska.

	Month												
Parameter	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Maximum Temperature(F)	-0.8	8.6	20.0	37.3	56.7	70.1	70.9	63.5	53.1	30.2	10.9	4.2	35.5
Mean Temperature (F)	-9.2	-1.1	8.4	26.1	45.4	58.6	60.6	54.4	44.1	23.6	4.4	-3.8	26.1
Minimum Temperature (F)	-17.6	-10.9	-3.2	14.8	34.0	47.2	50.4	45.3	35.0	17.0	-2.1	-11.7	16.6
Precipitation (inches)	0.66	0.66	0.57	0.31	0.40	1.43	1.97	2.23	1.42	1.06	0.77	0.89	12.37
Snowfall (inches)	12.0	14.7	10.1	4.6	0.4	0.0	0.0	0.0	0.4	8.6	13.0	14.1	77.9

(Source: ACRC, 2015)

2.4 Existing Wastewater Treatment Facilities in Galena

Wastewater is collected by sewage tank haul which is managed by the City of Galena. Sewage is hauled to one of two sewage lagoon facilities. A four cell partial-mix aerated lagoon is located at the former military base site. A two cell facultative lagoon is located at the new town site. Reporting data is only available for the partial-mix aerated lagoon located at the former military base.

Reporting data indicates that the partial-mix aerated lagoon is currently treating an average of 23,800 gpd. Over the eleven quarters data was available in the ECHO system the lagoon's compliance status was listed as either Significant Non-compliance or Violation (EPA, 2015). Parameters where the lagoon has not achieved permit requirements over the reporting period include BOD, TSS, and Dissolved Oxygen (DO) (EPA, 2015). As-built drawings of the lagoon indicated that at an average daily flow of 23,800 gpd the calculated performance of the lagoon is within the recommended design parameters for a partial-mix aerated lagoon. Table 2.2 summarizes the calculated performance for the partial-mix aerated lagoon along with recommended design parameters. Actual performance data for the partial-mix aerated lagoon indicates that the lagoon is not performing to the level that the calculated performance suggests.

Table 2.2: Calculated performance of existing partial-mix aerated lagoon and design parameters for partial mix aerated lagoons.

Parameter	Existing Partial-mix Aerated Lagoon Calculated Performance	Partial-mix Aerated Lagoon Recommended Design Parameters
Detention Time, days	43-129	5-20
Organic loading rate, lb/ac*day	14-164	40-360
Effluent characteristics		
BOD, mg/L	11-80	20-40
TSS, mg/L	10-112	30-60

(Source: Adapted from Crites and Tchobanoglous, 1998)

Actual performance data for the existing facultative lagoon at the new town site is not available. The ADEC permit for the facility indicates that it is a two cell lagoon which discharges to wetlands 1,900 feet from the Yukon River. Due to the lack of performance data the existing flow conditions were back calculated for the lagoon. Satellite imagery was used to estimate dimensions of the existing two cell facultative lagoon. The depth of the two cells was assumed to meet ADEC lagoon design requirements. The estimated dimensions were used to establish an assumed volume and a minimum HRT of 240 days was assumed which resulted in an assumed current average daily flow of 12,000 gpd. The estimated 12,000 gpd flow seems reasonable when combined with the known flow of 23,800 gpd at the partial-mixed aerated lagoon for a total assumed daily flow of 35,800 gpd.

Table 2.3: Calculated performance of existing facultative lagoon and design parameters for facultative lagoons.

Parameter	Existing Facultative Lagoon Calculated Performance	Facultative Lagoon Design Parameters
Detention Time, days	240	240-365
Organic loading rate, lb/ac*day	4	20

(Source: Adapted from Alaska Department of Environmental Conservation, 2009)

Chapter 3 Design Goals & Parameters

3.1 Introduction

In an effort to reduce the overall complexity of treatment an expansion of the facultative lagoon at the new town site with the addition of a constructed wetland is proposed in place of the two separate lagoons currently in use in Galena. It is known based on reporting data that the partial-mix aerated lagoon near the airport is not operating within permit requirements under current loading. It is expected that the facultative lagoon located at the new town site would also be unable to operate within permit requirements under total design load. It is possible the partial-mix aerated lagoon will need to remain in operation due to the likely piped flow into the lagoon from the former military facilities which now serve as the boarding school.

3.2 Site

The existing facultative lagoon at the new town site is located adjacent to a large undeveloped tract. The tract in located in a locally depressed area that generally slopes toward the tract and grades within the tract are mild. The undeveloped tract provides more than enough space for the proposed lagoon expansion and constructed wetland. The existing lagoon and undeveloped tract are shown in Figure 3.1.

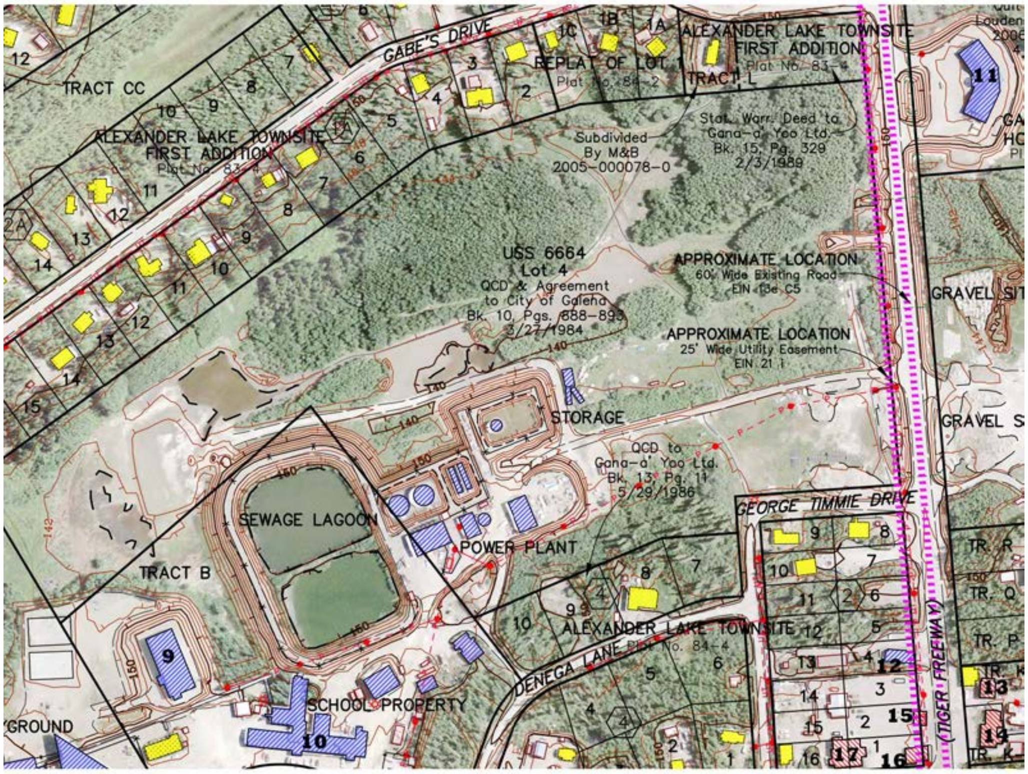

Figure 3.1: Proposed project site.
(Source: ADECD Community Map, Galena, AK, 2005)

3.3 Population and Flow

Based on Census data Galena's population peaked around 1990 when 833 residents were reported. The most recent census data from 2010 indicates the population has dropped to 470 residents (ADECD, 2015). The closure of the Air Force facility in 1993 certainly contributed to the decline in population.

Water distribution in Galena is a combination of piped and water deliver. The community's wastewater collection system currently consists of sewage tank haul. Typical sewage flow for a community with truck-haul systems is approximately 37 gpcd (Smith, 1996). At the current population this would result in an average daily flow of 17,390 gpd. This is not consistent with the reported average daily flow for the existing partial-mix aerated lagoon of 23,800 gpd (EPA, 2015). The existing partial-mixed aerated lagoon only receives wastewater from a portion of the community, which suggest the average sewage flow is well in excess of 37 gpcd.

Typical sewage flow from communities with piped water and sewer is estimated between 65-80 gpcd (Smith, 1996; Crites and Tchobanoglous 1998). At the current population 80 gpcd would result in an average daily flow of 37,600 gpd. Planning for a sewage flow consistent with a conventional piped system is prudent as most communities who are not on conventional piped systems intend to update their infrastructure to piped systems when resources are available. It is possible that the community will upgrade its collection system during the design life of the treatment system and an oversized system will allow the collection system upgrade without the need to upgrade the treatment system.

It is also prudent to prepare for the potential for population increase. At the historical peak population of 833 an average daily flow of 37,600 gpd would represent a per person flow of approximately 45 gpcd. This is more than the 37 gpcd that would be expected for a community with a truck haul collection system but considerably less than the 65-80 gpcd that would be expected from a community with a piped collection system. However, the average daily flow for a population of 833 and a per-capita flow of 80 gpcd is 66,640; this is an unreasonably large flow to design for.

Ultimately a design flow of 37,600 gpd has been used for the project partially due to the assumption that a portion of the wastewater flow will still go to the partial-aerated lagoon.

3.4 Design Parameters

The ADEC has permitting authority for wastewater treatment facilities in Alaska. The ADEC sets effluent limits and monitoring requirements. Typical parameters that require monitoring for facultative lagoons and constructed wetlands include flow, pH, DO, BOD, TSS, and fecal coliform bacteria (FC).

The ADEC sets effluent limits at specific monitoring points. Monitoring points may include the end of the treatment process as well as at the receiving body and at the edge of the receiving body mixing zone. For the Talkeetna Wastewater Lagoon the ADEC has established a single monitoring point at the end of the treatment process prior to discharge to the Talkeetna River Slough (ADEC, 2013). For the facultative lagoon at the Galena new town site the ADEC has set monitoring points at the end at the treatment process prior to discharge into wetlands as well as monitoring points at the shoreline point of discharge and edge of the receiving body mixing zone (ADEC, 2006). Ultimately when compared at the final monitoring point the effluent parameter limits are consistent between the Talkeetna Wastewater Lagoon and the Galena new town site facultative lagoon. Table 3.1 provides current effluent limits at the final monitoring point for the Talkeetna Wastewater Lagoon as well as the two cell facultative lagoon at the Galena new town site. The proposed design is based on meeting or exceeding the effluent parameters in Table 3.1.

Table 3.1: Effluent Limits for the Talkeetna Wastewater Lagoon and Galena New Town Site Lagoon at final monitoring points.

Effluent Parameter	Minimum Daily Limit	Average Monthly Limit	Average Weekly Limit	Maximum Daily Limit
pH, s.u.	6.5	N/A	N/A	8.5
Dissolved Oxygen, mg/L	7	N/A	N/A	17
5-Day Biochemical Oxygen Demand, mg/L	N/A	45	65	N/A
Total Suspended Solids, mg/L	N/A	70	N/A	N/A
Fecal Coliform Bacteria, FC/100 mL	N/A	20	N/A	40

(Source: Adapted from ADEC, 2006; ADEC, 2013)

3.5 Wastewater Characteristics

Raw wastewater characteristics for wastewater flows into the partial-mix aerated lagoon near the airport are available from the monitoring data (EPA, 2015). The values are consistent with conventionally diluted wastewater characteristics. The raw water characteristics for the partial-mix aerated lagoon near the airport are shown with characteristics of conventionally diluted wastewater in Table 3.2. The average raw wastewater BOD and TSS values from the ECHO data for the airport lagoon were selected for use in the design.

Table 3.2: Characteristics of raw wastewater at airport lagoon and conventionally diluted wastewater.

	Airport Lagoon		Conventionally Diluted	
Parameter	Average	Range	Average	Range
BOD, mg/L	322	68 - 2,050	220	110 - 400
TSS, mg/L	327	36 - 3,040	220	250 - 1,000
Total Nitrogen, mg/L as N	Unknown	Unknown	40	20-90
Phosphorus, mg/L as P	Unknown	Unknown	8	4-15

(Source: Adapted from Smith, 1996; EPA, 2015)

Chapter 4 Lagoon Design

4.1 Design Guidance

In 2009 the ADEC published lagoon construction guidelines. The guidelines include design requirements for lagoon service life, retention time, BOD loading, wastewater flows, BOD and TSS removal, and pathogen reduction (ADEC, 2009).

4.2 Service Life

The ADEC design requirement for service life is a minimum of 20 years with delineation of projected population growth and changes in wastewater conveyance (ADEC, 2009). Service life was considered when selecting a design average daily flow (ADF) for the treatment facility. The design ADF for the project is 37,600 gpd based on what is known of current flows, current and past population, current and future conveyance, and typical sewage flow rates.

4.3 Organic Loading

The ADEC design requirement for organic loading is a maximum rate of 20 lbs/acre/day (ADEC, 2009). A total surface area of 220,038 sf is required to achieve the maximum loading rate given the design flow and raw sewage concentration. The surface area of the existing two cell facultative lagoon at the new town site is 139,063 sf. The area of the proposed third cell is 81,000, which results in a total surface area of 220,063 sf.

4.4 Hydraulic Retention Time

The ADEC design requirement for HRT is a minimum 240 days up to a maximum of 365 days for a single, seasonal discharge (ADEC, 2009). The lagoon will operate with a 120 day discharge period. As a result the HRT for the lagoon must be at least 245 days. Given the design flow of 37,600 gpd the volume required to achieve an HRT of 245 days is 9,212,000 gallons. The estimated volume of the existing two cell facultative lagoon at the new town site is 5,376,800 gallons. The proposed third cell with an effective depth of 6.5 ft provides 3,938,500 gallons of volume which results in a total volume of 9,315,300 gallons and a total HRT of 248 days.

4.5 Biochemical Oxygen Demand and Total Suspended Solids Removal

The ADEC design requirements for BOD and TSS removal is a minimum 85% removal of each constituent (ADEC, 2009). This design parameter is based on a lagoon discharging to an outfall. The lagoon will discharge to the constructed wetland. Based on permit requirements at the Talkeetna Wastewater Lagoon the ADEC will not require reporting of effluent parameters at the lagoon effluent, only at the constructed wetland effluent. As a result this parameter was not considered in the design. The lagoon design is based on the organic loading and HRT design parameters only.

4.6 Pathogen Reduction

The ADEC design requirements for pathogen reduction require effluent to meet pathogen levels stipulated in the selected discharge permit for the site (marine or fresh water) (ADEC, 2009). The survival of pathogen indicator microorganism such as fecal coliform is longer in cold water than in warm water (Smith et al., 1996). As discussed in Section 5.9, meeting the ADEC permit requirement for fecal coliform concentration does not appear possible and additional treatment or a mixing zone is required.

4.7 Final Design

The project utilizes the two cells of the existing facultative lagoon at the new town site and adds a third cell to properly size the lagoon for the design flow. Table 4.1 summarizes the properties of the existing and proposed lagoon cells and Figure 4.1 shows the design on the proposed site.

Table 4.1: Facultative lagoon design summary.

Parameter	Cell #1 (Existing)	Cell #2 (Existing)	Cell #3 (Proposed)	Totals
Surface Area, sf	60,300	78,700	81,000	220,000
Volume, gallons	3,609,600	1,767,200	3,938,500	9,315,300
HRT, days	96	47	105	248

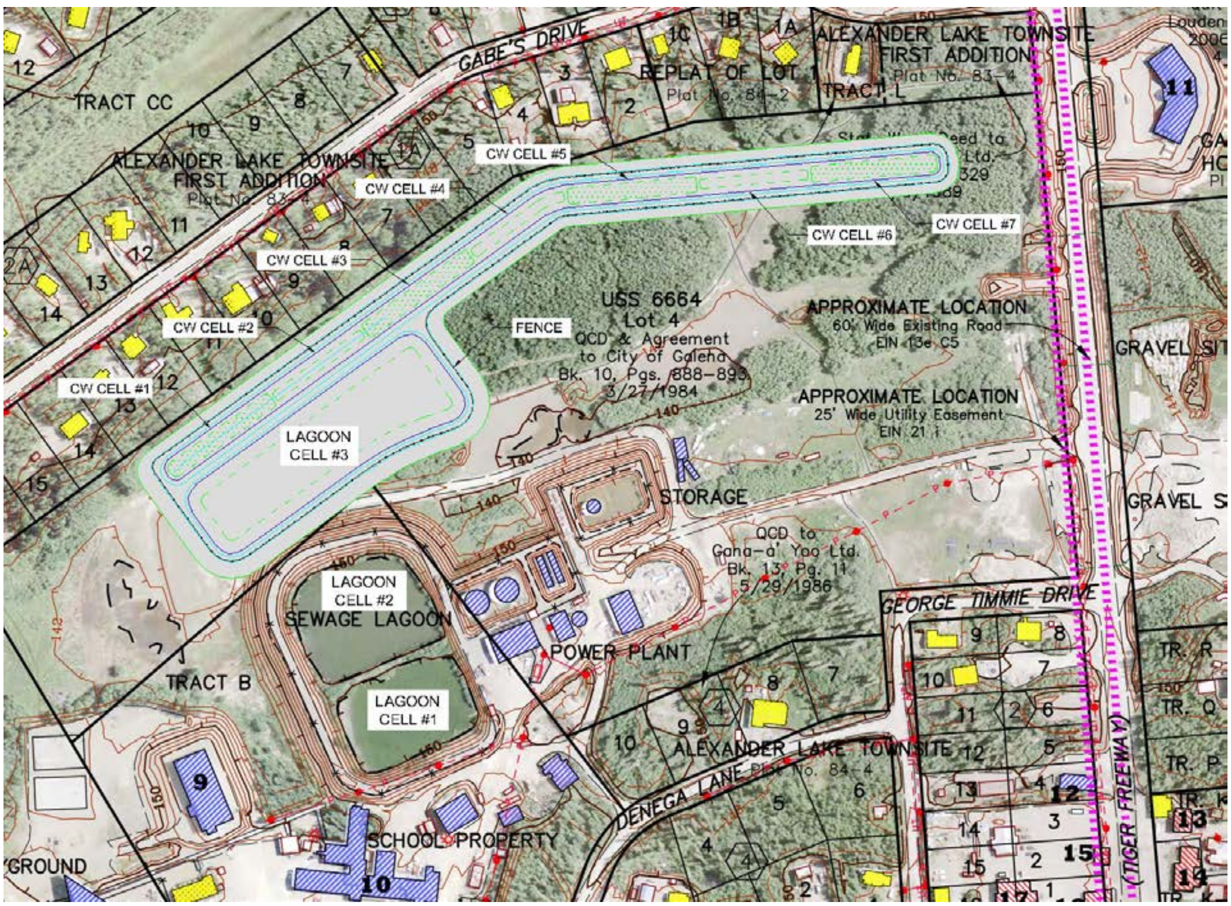

Figure 4.1: Plan view of proposed Lagoon Cell #3.

(Source: Adapted from ADECD Community Map, Galena, AK, 2005)

Chapter 5 FWS Constructed Wetland Design Introduction

5.1 Design Guidance

While it is thought that the use of wetlands in wastewater treatment has occurred as long as wastewater has been collected, research on the use of wetlands for wastewater treatment in the US didn't begin until the 1960's and increased throughout the 1970's and 1980's (EPA, 1999). Despite the decades of research much additional research is needed before the design of wetland treatment facilities can be considered scientific and routine (Crites and Tchobanoglous, 1998). Modeling the removal rate constants for wastewater constituents is difficult due to the varied nature of the wastewater constituents and the mechanisms involved in their removal. For instance influent may contain soluble, colloidal, and or particulate BOD and removal may occur via aerobic, anoxic, or anaerobic biological mechanisms and by flocculation or sedimentation (Crites and Tchobanoglous, 1998). As a result of the complexity of modeling individual constituent removal the design criteria typically provided in design guides are limited to organic loading, retention time, plant selection and sequencing, and dimensional characteristics. Data from existing constructed wetland wastewater treatment facilities serve as the basis for the typical design parameters that have been demonstrated to achieve permit requirements. The EPA design manual (1999) summarizes the difficulties in modeling constructed wetland treatment caused by the lack of accurate design parameters as follows:

> "The current trend in wetland design modeling is the development of simple mass balance or input/output models. These simplified models do not explicitly account for the many complex reactions that occur in a wetland, either in the water column or at the interfaces such as the water/sediment interface. Instead, all reactions are lumped into one overall biological reaction rate parameter that can be estimated from collected FWS wetland performance data" (EPA, 1999).

In 1988 the US Environmental Protection Agency (EPA) printed a design manual for constructed wetlands used in municipal wastewater treatment (EPA, 1988). The 1988 manual was superseded by a manual published in 1999 (EPA, 1999). The ADEC does not provide design parameters for wetland wastewater treatment and in the absence of that guidance this project will largely follow the EPA guidance.

The design methodology recommended in the EPA manual includes areal loading rates for BOD and TSS intended to meet permit required effluent concentrations along with recommendations for shape, dimensions, planting strategy, and design components targeted at removal of specific constituents.

The EPA design guidance recommends a minimum three cell configuration with alternating vegetated and open water cells. The initial cell is where the bulk of the flocculation and sedimentation will occur, the second open water cell is where soluble BOD reduction and nitrification can occur, and the final vegetated cell provides polishing and further reduction in TSS and associated constituents (EPA, 1999). The effect of each cell on the fate of wastewater constituents is shown in Figure 5.1.

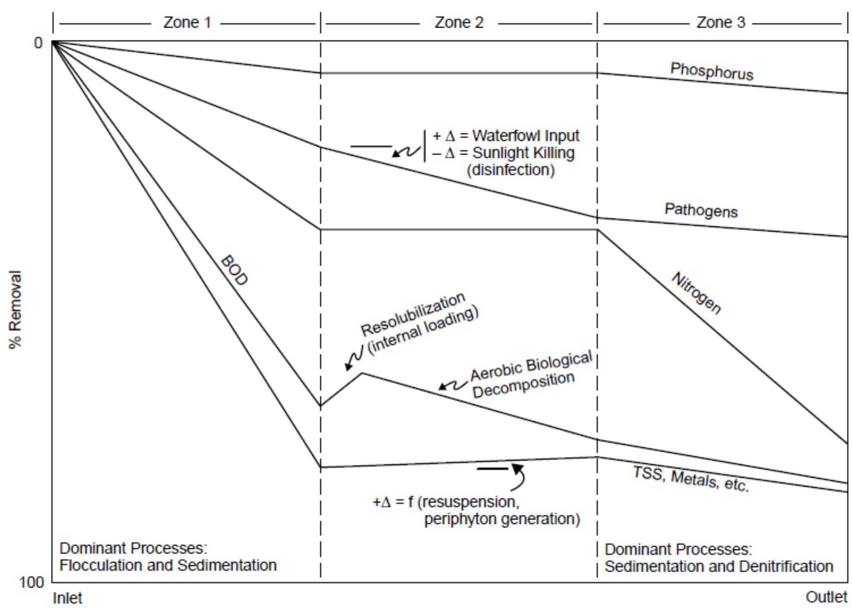

Figure 5.1: Generic removal of pollutants in FWS system.

(Source: EPA, 1999).

Additional cells may be used in larger treatment facilities with the vegetated and open water cells alternated but in all cases the EPA recommends vegetation in the first and last cells. The design guidance recommends that vegetated cells operate at a water depth of 2-feet and a HRT of 2 days and open water cells operate at a water depth of 4-feet and a HRT of 2-3 days. The open water cells may contain submergent aquatic plants as well as unconsolidated groups of floating aquatic plants. Northern climates can operate with longer HRT's in each zone due to slower kinetic reaction rates and slower algal growth (EPA, 1999). Figure 5.2 shows the mechanisms that occur in the FWS constructed wetland.

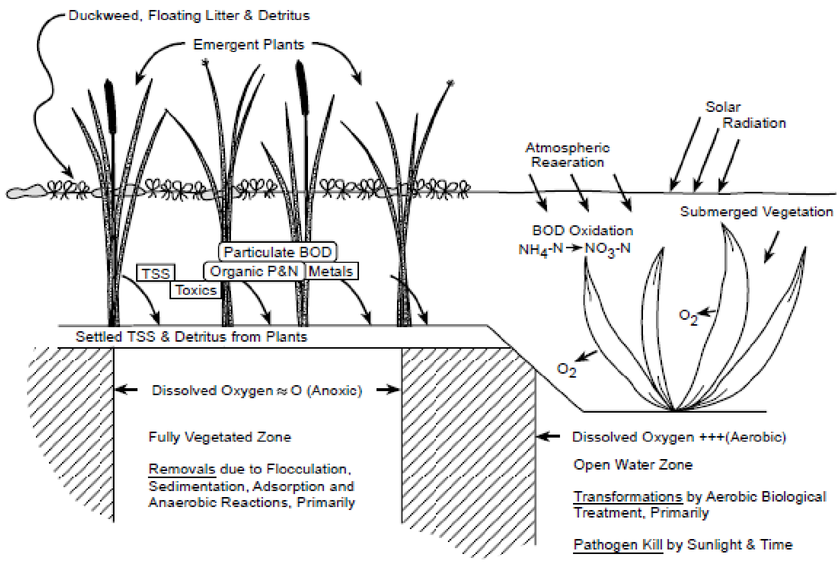

Figure 5.2: Mechanisms of FWS systems

(Source: EPA, 1999)

ADEC permitting requirements were discussed in Section 3.4. The EPA design manual provides guidance for designing a wetland treatment system that will comply with ADEC permitting requirements. The EPA recommended design criteria used for this project are summarized in Table 5.1.

Table 5.1: EPA recommended design criteria for effluent concentration of 30 mg/L BOD and 30 mg/L TSS.

Parameter	Design Criteria
BOD loading, kg/ha-d	60
TSS loading, kg/ha-d	50
HRT (vegetated cells), days	2
HRT (open water cells), days	2-3
Vegetated cell depth, m	0.6 – 0.9
Open-water cell depth, m	1.2 – 1.5
Aspect ratio	3:1 – 5:1

(Source: EPA, 1999)

5.2 Cold Regions Literature Review

The EPA design criteria are based on data from 21 sites treating oxidation pond and primary treated effluent. The 21 sites encompass a variety of communities in the Lower 48 and Canada but do not include communities in Alaska. The focus of this project is on rural Alaska and a review of literature relating to wetland treatment in cold climates was attempted. Limited useful literature was located and most focused on seasonal variations in Lower 48 climates. Recommendations found for the design of treatment systems for cold regions or winter season operation include increasing HRT and planting specific species of vegetation that provide apparent treatment benefits during cold temperatures and plant dormancy.

In a study conducted by Stein and Hook (2005) constituent removal was found to vary seasonally between several plant species as shown in Figure 5.3. The research actually suggested an increase in Carbonaceous Oxygen Demand (COD) removal with Carex (sedge), and Scirpus (bulrush), species during winter season conditions that the authors theorize may have resulted from the variation in root zone oxidation with the plants using more oxygen during emergent periods leaving less oxygen available for microbial respiration. Ultimately the authors conclude that seasonal variation of constructed wetland performance is heavily influenced by the presence or absence of plant species and temperature is at best a secondary predictor of constructed wetland performance (Stein and Hook, 2005).

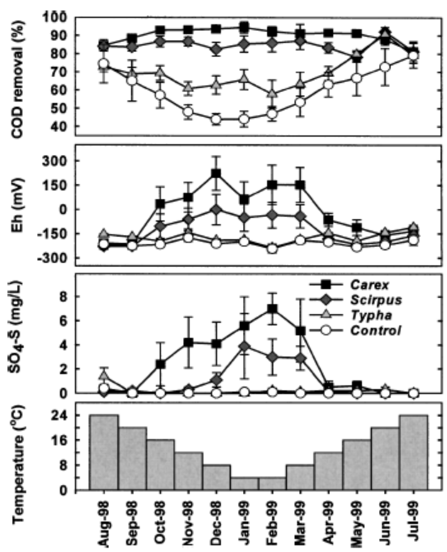

Figure 5.3: Seasonal variation of COD removal, Redox Potential (Eh), and sulfate concentration (Source: Stein and Hook, 2005).

In a study conducted by Kotti et al. (2010) a HRT of 14 days is recommended for general conditions and a HRT of 20 days is recommended for cold season conditions. The study also provides some general recommendations on designing constructed wetlands for wastewater treatment. One recommendation is distributing influent at various points along the treatment wetland (step feeding) to increase nitrification. The research also found higher COD and phosphorus removal from cattails, higher phosphorus removal from clay substrate compared to sand substrate, and increased performance from a wetland unit with a trapezoidal plan view shape (Kotti et al., 2010).

While not focused on seasonal or cold weather aspects of wetland design, a review of the sustainability of constructed wetlands for wastewater treatment by Wu et al. (2014) provides a summary of current recommended design parameters for FWS and SFS constructed wetlands. The recommended design parameters for FWS wetlands are summarized in Table 5.2.

Table 5.2: Recommendations for the design and operation of FWS constructed wetlands for wastewater treatment.

Parameter	Design Criteria
Bed size, m3	Larger if available
Length to width ratio	3:1 – 5:1
Water depth, m	0.3-0.5
Hydraulic slope, %	<0.5
Hydraulic loading rate, m/d	<0.1
Hydraulic retention time, day	5-30
Media	Natural media and industrial by-product preferred, porosity 0.3-0.3, particle size <20mm
Vegetation	Native species preferred, plat density 80% coverage

(Source: Wu et al., 2014).

Chapter 6 FWS Constructed Wetland Design Methodology

6.1 Areal Loading

The EPA design recommendation for BOD and TSS areal loading is a maximum rate of 60 kg/ha-day and 50 kg/ha-day respectively (EPA, 1999). Actual BOD and TSS influent concentrations are unknown. The EPA provides a table of typical constructed wetland influents in the design manual which includes typical constituent concentrations for pond effluent (EPA, 1999). Crites and Tchobanoglous (1998) also provide estimated effluent characteristics for BOD and TSS concentrations from facultative lagoons. The recommended design parameters are summarized in Table 6.1.

Table 6.1: Typical constituent concentrations in lagoon effluent.

Constituent	EPA	Crites and Tchobanoglous
BOD, mg/L	11-35	30-40
TSS mg/L	20-80	40-100

(Source: EPA, 1999; Crites and Tchobanoglous, 1998)

While TSS concentration is estimated at up to 80 mg/L by the EPA and 100 mg/L by Crites and Tchobanoglous, TSS concentration as high as 178 mg/L have been found in facultative lagoon effluent (EPA 1999; Crites and Tchobanoglous, 1998). The high TSS concentrations are due to algae growth that occurs in the lagoon. The estimated constituent concentrations of 40 mg/L for BOD and 100 mg/L for TSS from Crites and Tchobanoglous (1998) were selected for use in the design.

The limiting condition for areal loading was found to be the TSS loading with 1.45 acres required to achieve a loading rate of 50 kg/ha*day from a TSS concentration of 100 mg/L. A total constructed wetland surface area of 66,550 sf (1.53 acres) is provided in the proposed design.

6.2 Hydraulic Retention Time

The EPA design recommendation for HRT is 2 days for vegetated cells and 2-3 days for open-water cells (EPA, 1999). Kotti et al. (2010) recommends a total HRT of 14 days with an increase to 20 days for cold seasons. Wu et al. (2014) recommends a total HRT of 5-30 days. The proposed design provides a HRT of 2.3 days for each vegetated cell and 3.0 days for each open-water cell for a total HRT of 18.4 days. This is less than Kotti et al. (2010) recommends for cold seasons but, due to freezing conditions over much of the year, the proposed constructed wetland will only be in use during a 120 day annual thaw period. The 120 day treatment period will occur during the warmest period of the year and during a period of plant growth. As a result it does not seem necessary to extend the HRT to the recommended 20 days.

6.3 Biochemical Oxygen Demand

The removal mechanism of BOD in FWS constructed wetlands varies for soluble and particulate BOD. Soluble BOD is removed by biological activity and adsorption on plant and detritus surfaces suspended in the water column. The emergent plants cause particulate BOD to flocculate and low velocities allow the sedimentation and entrapment of the particulate BOD (Crites and Tchobanoglous, 1998).

Effluent BOD concentrations from the proposed constructed wetland will consist of a combination of residual BOD from the influent wastewater and background BOD resulting from plant decay and vector contributions (Crites and Tchobanoglous, 1998). The EPA manual provides estimated background concentrations for FWS constructed wetlands which have been summarized in Table 6.2. As the last cell in the proposed wetland consist of a fully vegetated zone a background concentration of 10 mg/L is assumed.

Table 6.2: Background concentrations of water quality constituents in FWS constructed wetlands.

Parameter	Range	Typical
TSS, mg/L	2 – 5	3
BOD[1], mg/L	2 – 8	5
BOD[2], mg/L	5 – 12	10
TN, mg/L	1 – 3	2
NH_4-N, mg/L	0.2 – 1.5	1
TP, mg/L	0.1 – 0.5	0.3
FC, cfu/100 ml	50 – 5000	200

[1] FWS with open-water and submergent and floating aquatic macrophytes

[2] Fully vegetated with emergent macrophytes and with a minimum of open water.

(Source: EPA, 1999)

The EPA manual (1999) provides the following equation for estimating the residual BOD from the influent wastewater:

$$\frac{C_e}{C_o} = \frac{1}{\left(1 + tK_p\right)^N}$$

Where: Co = influent BOD concentration, mg/L

Ce = effluent BOD concentration, mg/L

N = number of open-water zones in the FWS

t = HRT

Kp=Specific BODs removal rate constant = 0.15 $(1.04)^{T-20}$

A water temperature of 3-degrees Celsius was assumed (Smith et al., 1996). After applying the properties of the proposed wetland and an influent BOD concentration of 40 mg/L to the equation a residual BOD of 2.84 mg/L was calculated. As a result the total effluent BOD concentration is estimated at 12.84 mg/L. The total system reduction for BOD is estimated at 96 percent. With an estimated effluent concentration this far below the permit concentration of 45 mg/L it may be possible to considering reducing the size of the wetland during future design phases to reduce the overall capital and operations and maintenance costs.

6.4 Total Suspended Solids

Removal mechanisms for TSS primarily consist of flocculation and sedimentation in the water column and filtration in the interstices of the detritus. Filtration mechanisms include mechanical straining, chance contact, impaction, and interception. The bulk of the TSS are removed within 50 to 100 ft of the inlet (Crites and Tchobanoglous, 1998).

Effluent TSS concentrations from the proposed constructed wetland should also be expected to consist of a combination of residual TSS from the influent wastewater and background TSS. The typical background TSS as provided by the EPA manual (1999) is 3 mg/L as shown in Table 6.2. The removal of TSS by physical interactions within the wetland can be estimated by the following equation provided by Crites and Tchobanoglous (1998):

$$C_e = C_o\left[0.1139 + 8.4 \times 10^{-4}\left(L_w\right)\right]$$

Where: Co = influent TSS concentration, mg/L

Ce = effluent TSS concentration, mg/L

Lw = wastewater hydraulic loading rate, in/d

After applying the properties of the proposed wetland and an influent TSS concentration of 100 mg/L to the equation a residual TSS of 11.55 mg/L was calculated. As a result the total effluent TSS concentration is estimated at 14.55 mg/L. The total system reduction for TSS is estimated at 95 percent. With an estimated effluent concentration this far below the permit concentration of 70 mg/L it would be possible to considering reducing the size of the wetland during future design phases to reduce the overall capital and operations and maintenance costs.

6.5 Dissolved Oxygen

The constructed wetland will contain vegetated and open-water cells. The vegetated cells are expected to operate in largely anaerobic conditions while the open-water cells are expected to operate in aerobic conditions. A value near zero DO is considered normal in fully vegetated zones of FWS wetlands (EPA, 1999). DO concentration from cells in a real world wetland are shown in Figure 6.1. The DO concentrations in Figure 6.1 are from a polishing FWS wetland and are therefore higher than concentrations expected in a treatment wetland (EPA, 1999).

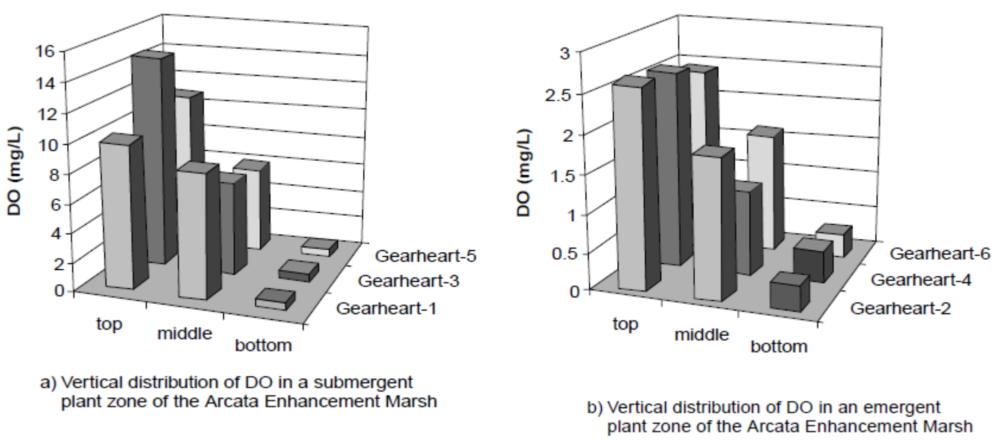

Figure 6.1: Dissolved oxygen distribution in emergent and submergent zones of a tertiary FWS. (Source: EPA, 1999)

The last cell in the proposed wetland will be a fully vegetated cell. The effluent from this cell may not comply with the ADEC requirement for a minimum effluent concentration of 7 mg/L (ADEC, 2006). Under the current ADEC permit the 7 mg/L concentration must be achieved at the receiving body monitoring point, so an effluent concentration less than 7 mg/L could be acceptable if reaeration occurs before discharge to the receiving body or the mixing zone.

While the DO concentration of the constructed wetland effluent may not meet the ADEC permit requirements, the reduction in BOD from the wetland will result in an effluent that will be more readily reaerated than the lagoon effluent would be without the constructed wetland. The effect of the oxygen sag on the receiving body is shown in Figure 6.2.

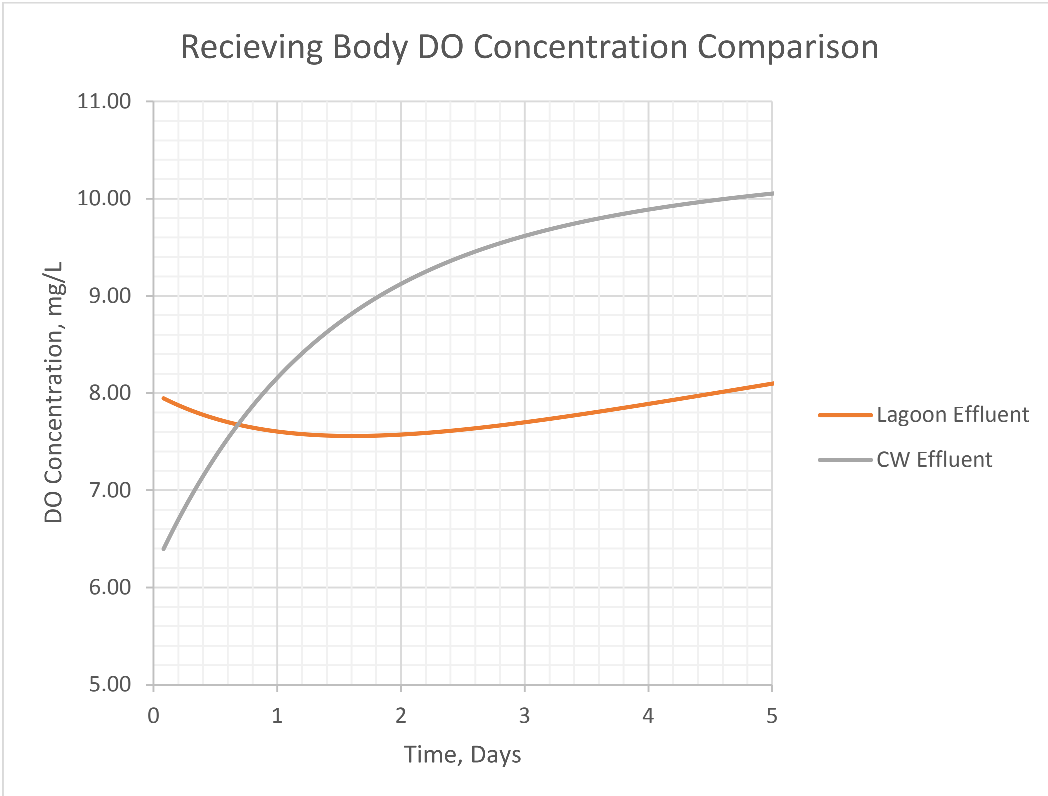

Figure 6.2: Comparison of receiving body DO: lagoon effluent verses constructed wetland effluent.

The receiving body was assumed to have a dissolved oxygen concentration of 8.0 mg/L and a flow of 1,000 m^3/d. The effect of mixing lagoon effluent with a BOD concentration of 40 mg/L, DO concentration of 8.0 mg/L, and flow of 294 m^3/d with the receiving body is shown in orange. The effect of mixing constructed wetland effluent with a BOD concentration of 12.8 mg/L, DO concentration of 0.0 mg/L and flow of 294 m^3/d with the receiving body is shown in grey. While the receiving body DO concentration is initially higher with the lagoon effluent, the receiving body DO concentration quickly recovers from the effect of the constructed wetland effluent at a DO concentration of 0.0 mg/L. In contrast, the lagoon effluent causes a sag in the DO concentration of the receiving body. In an effort to show the impact of DO and BOD concentration on the receiving body this comparison was done with a receiving body flowrate that is much less than is expected in the actual receiving body. This comparison used a flowrate of 0.01 m^3/s while the flowrate of the Yukon River ranges from approximately 1,500 to 20,000 m^3/s. The actual effect of the effluent on the Yukon River is negligible.

6.6 pH

The lagoon and constructed wetland treatment facility will receive domestic wastewater. Domestic wastewater is normally alkaline (Crites and Tchobanoglous, 1998). The pH range allowed by the ADEC permit is 6.5 to 8.5 at the receiving body monitoring point. Large changes in pH are not expected in the lagoon or constructed wetland. The only expected source of pH change is through photosynthesis. Active photosynthesis may raise pH to values as high as 8.0 to 8.5, which would still be within the ADEC permit levels (EPA, 1999).

6.7 Fecal Coliform

Removal of pathogens in constructed wetlands appears to occur by adsorption, sedimentation, predation, and die-off from unfavorable temperatures and exposure to sunlight (Crites and Tchobanoglous, 1998). Removal rates in constructed wetlands have been found to range from 90 to 99.9 percent (Crites and Tchobanoglous, 1998). However, indicator microorganisms survive longer in cold water than warm water (Smith et al., 1996). ADEC effluent criteria are also highly restrictive, requiring the reduction of FC concentrations to a maximum of 40 cfu/100 mL (ADEC, 2006). Considering raw wastewater may contain fecal coliform concentrations as high as 100,000,000 cfu/100 mL a removal rate of 99.9 percent may not be adequate to meet ADEC permit requirements (Crites and Tchobanoglous, 1998).

As with BOD and TSS, FC concentrations should also be expected to consist of a combination of residual FC from the influent wastewater and background FC. The typical background FC as provided by the EPA manual (1999) is 200 cfu/100 mL as shown in Table 6.2.

The estimated FC concentrations for lagoon effluent provided by the EPA manual (1999) range from 6 cfu/100 mL to 398,000 cfu/100 mL. The average of the concentration range is 200,000 cfu/100 mL. With such a large range it is impossible to know with any confidence what the concentration of the lagoon effluent will be. For the purposes of this project the average value of 200,000 cfu/100 mL was used.

The EPA manual (1999) provides the following equation for estimating the residual Fecal Coliform from the influent wastewater:

$$\frac{C_e}{C_o} = \frac{1}{\left(1 + tK_p\right)^N}$$

Where: Co = influent FC concentration, cfu/100 mL

Ce = effluent FC concentration, cfu/100 mL

N = number of open-water zones in the FWS

t = HRT

Kp=Specific BODs removal rate constant = 2.6 $(1.19)^{T-20}$

After applying the properties of the proposed wetland and an influent FC concentration of 200,000 cfu/100 mL to the equation a residual FC of 4,700 cfu/100 mL was calculated. As a result the total effluent FC concentration is estimated at 4,900 cfu/100 mL, which is far greater than the maximum permit requirement. The total system reduction for TSS is estimated at 99.9 percent.

FC is not regulated at the same point as BOD and TSS. BOD and TSS are typically only sampled at the end of the treatment works while FC may be sampled at the end of the treatment works as well as at the point of entry into the receiving body mixing zone and at the edge of the receiving body mixing zone (ADEC, 2006). The current permit for the facultative lagoon at the new town site requires fecal coliform concentrations shown in Table 6.3 at the various sampling points.

Table 6.3: Fecal coliform permit requirements at sampling points: existing facultative lagoon at Galena new town site.

Sampling Point	Monthly Average	Weekly Average	Max Value
End of treatment works, cfu/100 mL	200	400	800
Point of entry for receiving body, cfu/100 mL	100	N/A	200
Edge of receiving body mixing zone, cfu/100 mL	20	N/A	40

(Source: EPA, 2006)

The ability to sample at multiple locations and to be held to the most restrictive permitting requirement only at the edge of the mixing zone as opposed to at the end of the treatment works allows some needed relief from a very low allowable concentration level and a constituent that is very difficult to accurately predict.

In a real world application sampling would be conducted to establish actual FC concentrations on which to base the design. Without the benefit of additional information this hypothetical project should proceed under the understanding that FC concentrations may initially not meet permitting requirements. If effluent concentrations do not meet DEC requirements chlorination, ozonation, or UV disinfection could be added to the treatment process to bring FC concentrations down to permit levels. Alternatively a larger mixing zone could be negotiated with the ADEC.

6.8 Plants

The three primary categories of wetland vegetation of concern for constructed wetlands are submerged, floating, and emergent plants, the plant types are shown in Figure 6.3. The vegetated cells will be planted with emergent plants. The open water cells will not be planted. The depth of the open water cells will discourage the migration of emergent vegetation into the open water cells (EPA, 1999).

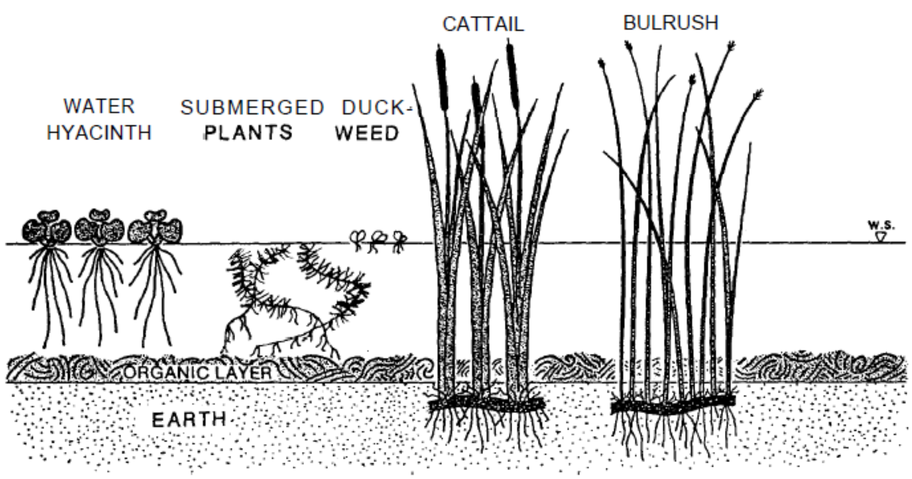

Figure 6.3: Common aquatic plants.

(Source: EPA, 1988)

Important considerations for plant selection include local availability, expected performance, and survivability. Plants that have been studied or used for wastewater treatment in Alaska include buckbean (Menyanthes trifoliatia), bulrush (Scirpus validus), carex (a type of sedge or grasslike plant), cattail (Typha latifolia), and pendant grass (Arctophila fulva) (Helfferich, 2004). Emergent plants that are expected to occur naturally in the Galena area include buckbean, red-tinge bulrush, broad-leaf cattail, and up to 76 species of carex (Lichvar, 2014).

Local availability will have a large impact on what plants are ultimately selected for use in the proposed constructed wetland. A combination of sedges and bulrush would be preferred. Cattail would also be acceptable.

6.9 Media

A soil medium is necessary in a constructed wetland primarily for the support of wetland vegetation (EPA 1999). Studies have found at least some ability for media to provide a surface that will support adsorption and precipitation of wastewater constituents. For instance, Kotti et al. (2010) found clay contributed to higher phosphorus removal than sand.

The site of the proposed additional lagoon cell and constructed wetland is undeveloped and largely vegetated. When the site is cleared and grubbed the existing surface organics can be separated and stockpiled for use in the constructed wetland. A layer of soil at least 6-inches deep is recommended (EPA, 1999). The entire area of disturbance for the new lagoon cell and constructed wetland will be cleared and grubbed but the new lagoon cell will not require media. This should result in enough excess organic soils to supply the constructed wetland with at least 6-inches of media.

6.10 Operation

The constructed wetland will operate during a 120 day thawed period from approximately mid-May to mid-September. The constructed wetland will be drawn down for the cold season to avoid damage to the plants from moving ice and to decrease the amount of frozen water that will accumulate in the constructed wetland.

Recirculation and step influent piping will be provided to allow increased operational control. The step influent piping will consist of an influent at the head of each vegetated cell as shown in Figure 6.4. Additional piping with be provided to draw the open water cells down for maintenance and annual freeze up.

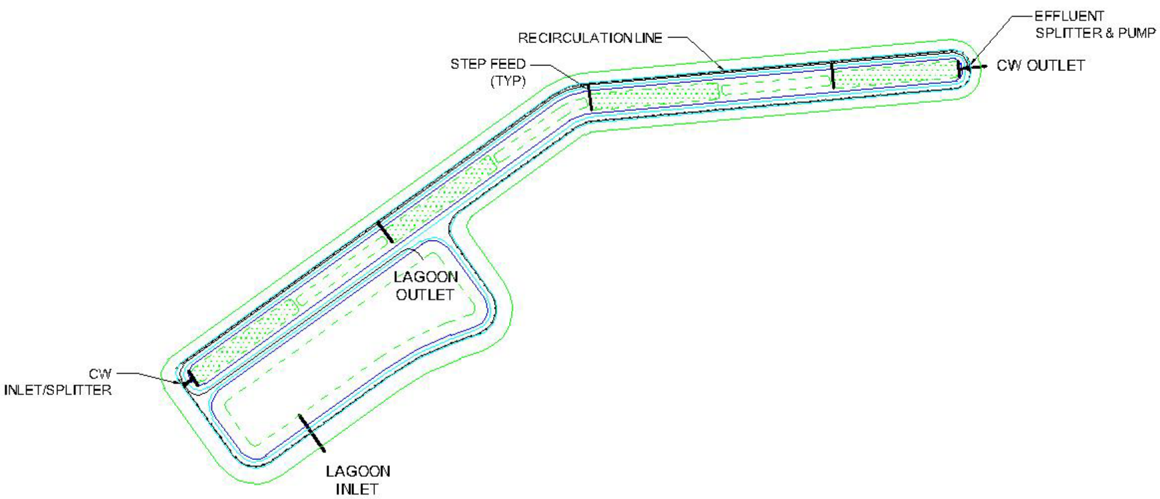

Figure 6.4: Proposed constructed wetland pipe schematic.

Operation of the constructed wetland is largely a matter of maintaining proper water level and flow control. Maintenance of the constructed wetland will largely consist of routine inspection of the inlet and outlet structures, berms and dikes, and control of nuisance pests. The wetland vegetation community will be largely self-maintaining. The plant community will grow, die, and regrow each year and plants will naturally spread to suitable unvegetated areas. The depth of the open-water cells will discourage emergent plants from spreading into the open-water cells (EPA, 1999).

6.11 Final Design

The project will include the construction of a new 81,000 sf lagoon cell which will serve to provide additional capacity at the existing facultative lagoon at the new town site, and a 65,200 sf constructed wetland. The properties of the existing lagoon facility along with the properties of the proposed lagoon cell are summarized in Table 4.1. The properties of the proposed constructed wetland are summarized in Table 6.4. The estimated influent and effluent concentrations of permitted wastewater constituents is summarized in Table 6.5. Plan and profile views of the proposed lagoon expansion and constructed wetland are provided in Figures 6.5 and 6.6.

Table 6.4: Constructed wetland design summary.

Parameter	Vegetated cells (cells 1, 3, 5, &7)	Open-water cells (cells 2, 4, & 6)	Total Constructed Wetland
Surface area, sf	10,000	8,400	65,200
Volume, gallons	181,500	233,400	1,607,700
HRT, days	2.3	3.0	18.4

Table 6.5: Estimated influent and effluent concentrations of permitted wastewater constituents.

Parameter	Estimated Influent	Estimated Effluent
BOD, mg/L	40	12.8
TSS, mg/L	100	14.5
DO, mg/L	Unknown	0
pH	Unknown	≤8.5
FC, cfu/100 mL	200,000	4,900

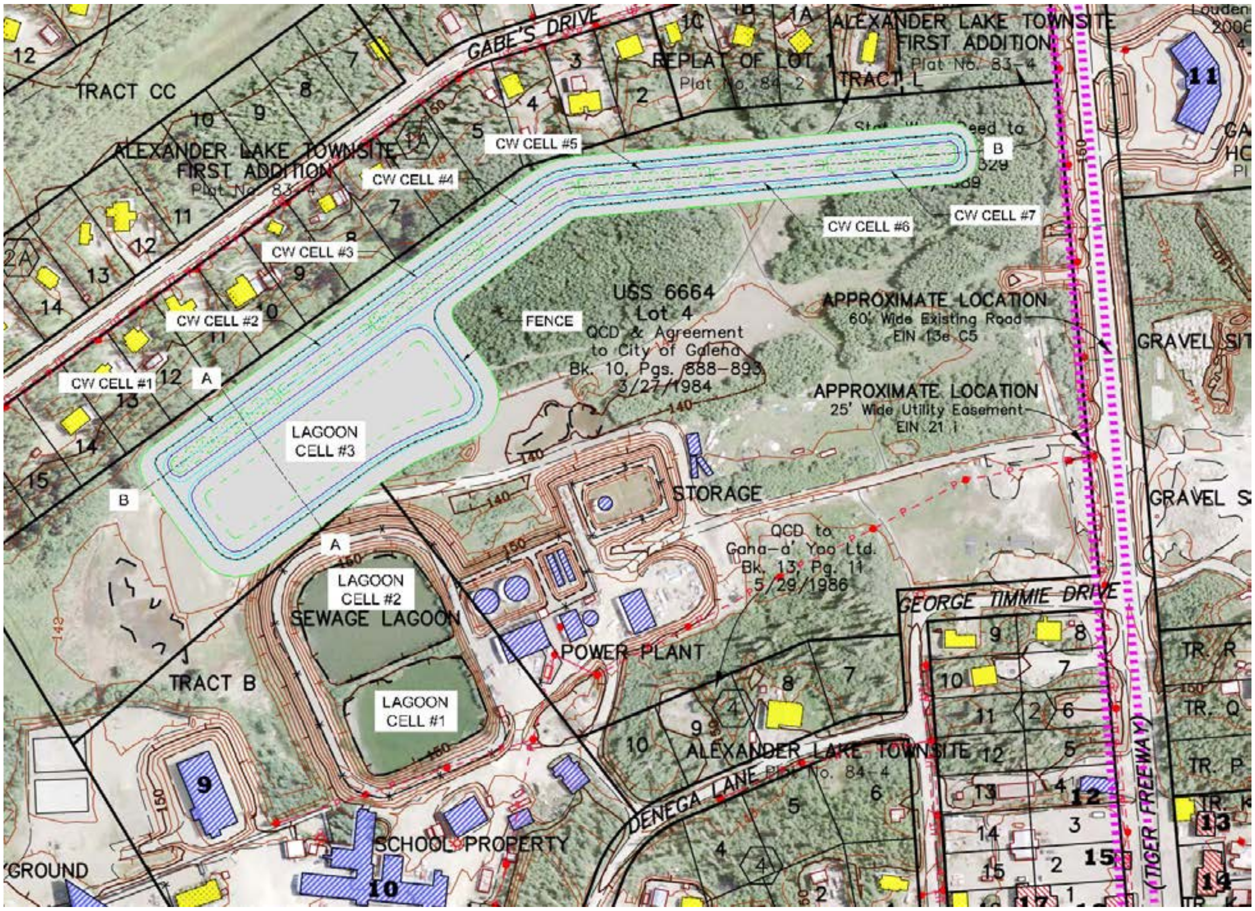

Figure 6.5: Plan view of proposed Lagoon Cell #3 and Constructed Wetland
(Source: Adapted from ADECD Community Map, Galena, AK, 2005)

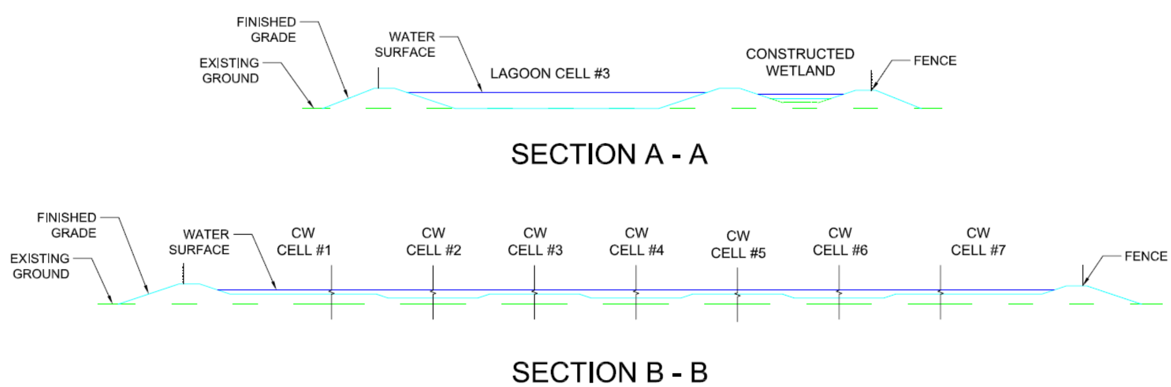

Figure 6.6: Cross sections of proposed Lagoon Cell #3 and Constructed Wetland.

Chapter 7 Cost Estimate

7.1 Capital Cost

Estimating construction costs at a feasibility design level is a difficult task that requires a designer to make assumptions and use professional judgment. Estimating construction costs in rural Alaska creates additional challenges. Many communities are located off the road system and are only accessible by airplane or barge. Temporary housing is often unavailable and the cost of commodities such as fuel, electricity, and food is typically much higher than the same commodities in communities that have road access. The intent of this estimate is to provide an order-of-magnitude preliminary estimate.

For this project the starting point for estimating construction costs was the EPA design manual (1999). The manual includes a section on estimating capital and operations and maintenance costs. The costs provided in the EPA manual (1999) are based on a Lower 48 project and are adjusted to 1997 dollars. These costs were adjusted to represent 2015 rural Alaska construction costs by using the factors shown in Table 7.1.

Table 7.1: Cost adjustment factors.

Adjustment Type	Adjustment Factor	Source
Consumer Price Index, 1997 to 2015	1.46	US Bureau of Labor and Statistics (2015)
Geographic Cost Multiplier, Anchorage	1.32	Sweets Unit Cost Guide (2012)
Rural Alaska Cost Multiplier, Anchorage to Bethel	1.66	Alaska Housing Finance (Kreiger et al., 2014)

The EPA manual (1999) costs are provided in units of $/hectare. These costs were converted into $/acre. The total footprint for the constructed wetland and proposed lagoon cell is 6.92 acres. Of the 6.92 acres 3.94 acres is the constructed wetland and 2.98 acres is the proposed lagoon cell. The estimated direct construction costs for the constructed wetland and proposed lagoon cell are provided in Table 7.2. Additional costs that are not included in the unit items provided in Table 7.2 are shown in Table 7.3.

Table 7.2: Direct construction costs for proposed Lagoon Cell #3 and Constructed Wetland.

Item	Unit	EPA Average Unit Cost (1997)	Alaska Adjusted Unit Cost (2015)	Constructed Wetland		Lagoon Cell #3	
				Area (acres)	Item Cost	Area (acres)	Item Cost
Survey/Geotechnical	$/acre	1,651	5,282	3.94	$20,812	2.98	$15,741
Clear & Grub	$/acre	3,503	11,205	3.94	$44,148	2.98	$33,391
Earthwork	$/acre	9,708	31,056	3.94	$122,361	2.98	$92,547
Membrane Liner, 40 mil PPE	$/acre	22,918	73,317	3.94	$288,869	2.98	$218,485
Media	$/acre	66,601	213,068	3.94	$839,488	2.98	N/A
Plants & Planting	$/acre	5,254	16,809	3.94	$66,228	2.98	N/A
Control Structures	$/acre	4,253	13,607	3.94	$53,612	2.98	$40,549
Plumbing & Fencing	$/acre	7,005	22,411	3.94	$88,300	2.98	$66,785
Total Direct Construction Costs				$1,523,818		$467,498	

(Source: Adapted from EPA, 1999)

Table 7.3: Total capital project cost for proposed Lagoon Cell #3 and Constructed Wetland.

Item	Item Cost
CONSTRUCTED WETLAND Total Direct Construction Cost	$1,523,818
Lagoon Total Direct Construction Cost	$467,498
Total Project Direct Construction Cost (TDCC)	$1,991,316
Miscellaneous Costs	
Mobilization (5% TDCC)	$99,566
Bonds (3% TDCC)	$59,739
Total Capital Construction Costs (TCCC)	$2,150,621
Engineering Design (15% TCCC)	$322,593
Construction Services and Startup (10% TCCC)	$215,062
Contractor’s Overhead and Profit (15%TCCC)	$322,593
Contingencies (15% TCCC)	$322,593
Total Capital Project Cost	$3,334,000

(Source: Adapted from EPA, 1999)

As shown in Table 7.3 the estimated total capital project cost for the proposed lagoon expansion and constructed wetland is $3,334,000. This cost is based on a feasibility level design and a combination of several cost adjustments intended to project rural Alaska construction costs in 2015 from Lower 48 construction costs from 1997.

7.2 Operation and Maintenance Cost

The EPA manual (1999) provides annual operations and maintenance costs for several constructed wetlands facilities located in the Lower 48. As with the capital cost estimate, the adjustment factors from Table 7.1 were applied to the Operations and Maintenance (O&M) costs in the EPA manual (1999) to estimate 2015 rural Alaska costs. These costs are summarized in Table 7.4.

Table 7.4: Operation and maintenance cost range.

Location	Unit	EPA Average Unit Cost (1997)	Alaska Adjusted Unit Cost (2015)
Ouray, CO	$/acre	1,365	4,367
Gustine, CA	$/acre	820	2,623
Ten Stones, VT	$/acre	1,638	5,240
Carville, LA	$/acre	1,016	3,250
		Average	3,870

(Source: Adapted from EPA, 1999; BLS, 2015; Sweets, 2015; AHF, 2014)

The adjusted O&M costs from Table 6.4 were applied to the proposed lagoon expansion and constructed wetland areas, as shown in Table 7.5. The result is an annual estimated O&M cost of $21,706. Over the course of the 20 year design life the O&M costs may total as much as $434,120.

Table 7.5: Estimated O&M costs for proposed Lagoon Cell #3 and Constructed Wetland.

	Constructed Wetland		Lagoon Cell #3		
Alaska Adjusted Unit Cost (2015), $/acre	Area, acres	Annual O&M Cost	Correction for Lagoon Costs (0.56)	Area, acres	Annual O&M Cost
3,870	3.94	$15,248	$2,167	2.98	$6,458

Chapter 8 Conclusion

The results of this project confirm the possibility of improving facultative lagoon effluent in rural Alaska by treatment in a constructed wetland. In the design example used in this project an expansion of the existing facultative lagoon was necessary to provide the storage to limit discharge to a 120 day thawed period. Communities with existing facultative lagoons large enough to provide storage for at least 240 days could benefit from the addition of a constructed wetland without the added cost of a lagoon expansion. When properly designed and executed a constructed wetland can remove the treatment variability that communities experience with facultative lagoons and allow more regular compliance with ADEC permit requirements.

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